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Soil Guideline Values for cadmium in soil

Science Report SC050021 / Cadmium SGV

This technical note is one in a series that describe Soil Guideline Values (SGVs) for individual, or groups of similar, chemicals to assist in the assessment of risks from land contamination.

SGVs are an example of generic assessment criteria (Defra and Environment Agency, 2004) and can be used in the preliminary evaluation of the risk to human health from long-term exposure to chemicals in soil. Specifically, this note provides SGVs for inorganic forms of cadmium in soil. It does not include organic cadmium compounds, which are unlikely to be found in soil.

The SGVs and the additional advice found here should be used only in conjunction with the introductory guide to the series entitled *Using Soil Guideline Values* (Environment Agency, 2009a), the framework documents *Updated technical background to the CLEA model* (Environment Agency, 2009b) and *Human health toxicological assessment of contaminants in soil* (Environment Agency 2009c), and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Cadmium* (Environment Agency, 2009d). Supplementary information on cadmium is also available (Environment Agency, 2009e).

All notes in the SGV series, the introductory guide and further supplementary information can be downloaded from our website (http://www.environment-agency.gov.uk/clea).

Cadmium and its compounds
In its elemental form, cadmium (CAS No. 7440-43-9) is a silver-white coloured, lustrous metal that can be easily cut by a knife at room temperature (MERCK, 2006; ATSDR, 2008). Cadmium metal will slowly oxidise in moist air to form cadmium oxide (CAS No. 1306-19-0), which is a greenish-yellow, brown through red to black crystalline solid or powder (MERCK, 2006; ECB, 2007).[i]

Cadmium has a relatively low crustal abundance, although it does occur ubiquitously in rocks and soils (Alloway, 1995; ECB, 2007). It is found rarely in its elemental form, with greenockite (CdS), octavite (CdSe), and monteponite (CdO) being its principal minerals (Kabata-Pendias and Mukherjee, 2007). Cadmium is often found in association with zinc-bearing and zinc-bearing lead ores, which are the main source of cadmium production (Greenwood and Earnshaw, 1997; ECB, 2007; ATSDR, 2008).

Cadmium has a similar chemistry to zinc with a strong affinity for sulphur (Alloway, 1995; Greenwood and Earnshaw, 1997; Kabata-Pendias and Mukherjee, 2007). Its compounds almost exclusively involve the +2 oxidation state and may be highly coloured (Greenwood and Earnshaw, 1997). Cadmium forms simple salts with oxygen, sulphur and many common anions including chloride, nitrate and carbonate (Greenwood and Earnshaw, 1997). In aqueous solution, cadmium often forms simple hydrated hxdroxyl ions such as $[Cd(OH)(H_2O)_x]^+$ it also has an appreciable coordination chemistry with ligands including halides, hydroxides, cyanides and nitrate, although the range is much less extensive than for other transition metals (Alloway, 1995; Greenwood and Earnshaw, 1997). Organocadmium compounds are rather reactive and unstable to both air and water, though they have been used to prepare ketones from acid chlorides (Greenwood and Earnshaw, 1997).

The primary commercial source of cadmium is as a by-product from the processing of zinc ores including sphalerite and smithsonite (Alloway, 1995; ECB, 2007). Historically, cadmium metal was recovered from the smelting of zinc ores by fractional distillation under reducing conditions to increase its purity.

The current practice in most European countries involves the electrolytic treatment of cadmium sulphate solution collected during the production of zinc (ECB, 2007).

Between 2000 and 2002, about 1,100 tonnes per year of cadmium was produced by European countries with a further 1,700 tonnes per year imported from outside the European Union (ECB, 2007).

A small but important proportion of cadmium, primarily from batteries, is recycled (ECB, 2007).

Cadmium oxide is an important industrial chemical, manufactured by the reaction of metal vapour with air (ECB, 2007). About 4,500 tonnes per year of cadmium oxide were produced across the European Union between 2000 and 2002 (ECB, 2007).

Cadmium metal, its alloys and compounds have been used in a variety of different industrial and consumer products, although most uses are now declining due to concerns about its toxicity (ATSDR, 2008). Currently, most cadmium is used in the production of nickel–cadmium batteries for industrial and commercial use although alternative products such as lithium ion batteries have eroded their market share in recent years (ECB, 2007; ATSDR, 2008). Cadmium is also still used as a semi-conductor and a photo-conductor in solar cells and other electronic devices (ATSDR, 2008).

Cadmium has also been used in pigments for plastics, glass and ceramics, as a fungicide, in stabilisers for plastics including PVC, and in corrosion-resistant coatings on steel and other non-ferrous metals; it has other minor applications for photography, photocopying, dyeing, calico printing, vacuum tube manufacture, galvanoplasty, lubricants, ice-nucleation agents, and in the manufacture of special mirrors (Alloway, 1995; ECB, 2007; Kabata-Pendias and Mukherjee, 2007; ATSDR, 2008).

According to a mass balance analysis of production, imports and exports for the period 2000 to 2002, the European Union used around 2,300 tonnes of cadmium with some 80 per cent used to make Ni–Cd batteries, and the remaining 20 per cent used for pigments, stabilisers, and alloys/metal plating (ECB, 2007).

Potential harm to human health

The principles behind the selection of Health Criteria Values (HCVs), and the definition of concepts and terms used, are outlined in *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c). Specific information on the toxicity of cadmium and its compounds is reviewed in *Contaminants in soil: updated collation of toxicological data and intake values for humans. Cadmium* (Environment Agency, 2009d) and only a brief summary is presented here.

Following long-term exposure to cadmium, the main health concerns are its toxicity to the kidney and bones, arising via ingestion and inhalation, and its lung carcinogenicity seen in exposed workers following inhalation (Environment Agency, 2009d).

Over a period of time, cadmium accumulates in the kidney and, if the organ concentration exceeds a critical threshold, the tubule cells become damaged and renal function impaired (Environment Agency, 2009d).

This cadmium build-up also affects vitamin D metabolism, disturbing the calcium balance within the body, which may lead to a decrease in the mineral content within the bones, resulting in osteoporosis and osteomalacia (Environment Agency, 2009d).

The oral tolerable daily intake (TDI_{oral}), which is based on an evaluation by the European Food Safety Authority (EFSA), is protective of renal and bone health effects (Environment Agency, 2009d).

The inhalation tolerable daily intake (TDI_{inh}), which is based on the proposal of a European Commission Working Group, is again protective of renal health effects. Exposure at this level is expected to pose a minimal risk of lung cancer (Environment Agency, 2009d).

Table 1
Recommended Health Criteria Values and estimated background adult intakes for inorganic compounds of cadmium (Environment Agency, 2009d)

Parameter	Cadmium
TDI_{oral}, µg kg^{-1} bw day^{-1}	0.36
MDI_{oral}, µg day^{-1}	13.4
TDI_{inh}, µg kg^{-1} bw day^{-1}	0.0014
MDI_{inh}, µg day^{-1}	0.02

Notes
bw = bodyweight
TDI = tolerable daily intake
MDI = mean daily intake

Health Criteria Values (HCVs) for cadmium and its inorganic compounds are summarised in Table 1.

The adult oral mean daily intake (MDI_{oral}) for cadmium is estimated at 13.4 µg day^{-1}. The adult inhalation mean daily intake (MDI_{inh}) is approximately 0.02 µg day^{-1} (Environment Agency, 2009d).

The effects of dermal exposure to cadmium are not expected to be significant and no expert group derivations of HCVs for dermal exposure were identified (Environment Agency, 2009d). Dermal absorption appears to be lower than oral absorption and, on this basis, it would seem reasonable to assume that the oral TDI for deriving SGVs could be used for an initial conservative dermal risk assessment, in line with Environment Agency (2009c).

Oral, dermal and inhalation exposures contribute to the same systemic effects on the kidney and bone; therefore, this should also be considered in a risk assessment.

Exposure assessment

Occurrence in soil

Cadmium occurs naturally in soils as a result of the weathering of the parent rock (Alloway, 1995). Sedimentary rocks have the greatest range of cadmium concentrations with the highest values found in sedimentary phosphate deposits and black shales (Alloway, 1995). Although most natural soils contain less than 1 mg kg^{-1} cadmium from the weathering of parent materials, those developed on black shales and those associated with mineralised deposits can have much higher levels (Alloway, 1995).

Anthropogenic sources of cadmium are much more significant than natural emissions and account for its ubiquitous presence in soil (Alloway, 1995; ECB, 2007; ATSDR, 2008). Cadmium is a trace element in phosphatic fertilisers, which have been applied extensively to arable and pasture land in the UK for decades (Alloway, 1995). ECB (2007) reported that current fertilisers contain around 79 mg of cadmium per kilogram of phosphorus. Based on the use of fertilisers in the 1980s and early 1990s, Alloway (1995) estimated that around 4.3 g of cadmium per hectare per year has been added to agricultural soils in the UK. Across the European Union, 231 tonnes of cadmium are added to agricultural soils each year from fertiliser use (EC, 2007).

Atmospheric deposition is also an important source of cadmium pollution (Alloway, 1995; ECB, 2007; ATSDR, 2008). The major sources of atmospheric emissions are non-ferrous metal production, fossil fuel combustion, waste incineration, and iron and steel production (Alloway, 1995; ATSDR, 2008). A representative deposition rate to agricultural land across the European Union has been estimated to be 3 g of cadmium per hectare per year (Alloway, 1995; Kabata-Pendias and Mukherjee, 2007).

Other sources of cadmium contamination include the application of sewage sludge, and metalliferous mining and smelting of zinc and sulphide ores (Alloway, 1995; ECB, 2007; ATSDR, 2008). Although these are relatively small contributors to global cadmium pollution,[1] these sources can be regionally and locally highly significant. For example, the soils of a village in southwest England were found to be highly contaminated with zinc, lead and cadmium as a result of the local mining of zinc during the 18th and 19th centuries (Alloway *et al*., 1988).

The UK Soil and Herbage Survey (UK SHS) is a comprehensive survey of the concentrations of major contaminants in soils and herbage across the UK. The UK SHS found total cadmium concentrations in the range 0.1 to 1.8 mg kg^{-1} dry weight (DW) for rural soils, with a mean of 0.39 mg kg^{-1} (Environment Agency, 2007). This is broadly consistent with the mean value of 0.49 mg kg^{-1} DW found by Spurgeon *et al*. (2008), who collected more than 1,000 samples from across the UK from predominately rural locations. A similar distribution was found in the UK SHS for urban soils, with a range of 0.1 to 2.39 mg kg^{-1} DW and a mean of 0.44 mg kg^{-1} (Environment Agency, 2007).

The difference in cadmium soil concentrations across the UK has been attributed to a probable higher prevalence and closer proximity to activities generating cadmium contamination (e.g. lead and zinc mining or associated smelting) rather than the more widespread use of phosphate fertilisers or use of sewage sludge on land (Environment Agency, 2007).

Behaviour in the soil environment

Recommended values for chemical data used in the exposure modelling of cadmium and its inorganic compounds are shown in Table 7. Further information about the selection of chemical properties and the derivation of the soil-to-plant concentration factors for inorganic compounds of cadmium can be found in *Supplementary information for the derivation of SGV for cadmium* (Environment Agency, 2009e).

Several studies have observed that cadmium concentrates in the surface horizon, most likely due to the combination of the sources of pollution (primarily fertiliser application and atmospheric deposition) and the higher near-surface levels of organic matter to which it readily binds (Alloway, 1995; ATSDR, 2008).

The soil chemistry of cadmium is based on the divalent cation (Cd^{2+}). The hydrated free cation is the main species of cadmium in soil solution, but it is also known to form complex ions with chloride ($CdCl^+$, $CdCl_3^-$, $CdCl_4^{2-}$), hydroxyl groups [$CdOH^+$, $Cd(OH)_3^-$, $Cd(OH)_4^{2-}$], and bicarbonate, as well as neutral soluble species such as cadmium sulphate ($CdSO_4$) and cadmium chloride ($CdCl_2$) Alloway, 1995; Kabata-Pendias and Mukherjee, 2007). Soluble and insoluble complexes with organic matter can also be important, although cadmium forms less stable complexes with humic and fulvic acids than those formed by copper and lead (Alloway, 1995; Kabata-Pendias and Mukherjee, 2007).

Surface adsorption processes rather than precipitation appear to control the distribution of cadmium between soil solution and soil-bound forms at the concentrations relevant to most polluted soils (Alloway, 1995). At extremely high cadmium concentrations, however, the precipitation of phosphates and carbonates could be expected (Alloway, 1995). Under anaerobic conditions, cadmium in soil solution may be controlled by the formation of insoluble sulphides (Kabata-Pendias and Mukherjee, 2007).

Adsorption of cadmium by soil depends strongly on pH, with its mobility decreasing with increasing alkalinity (Anderson and Christensen, 1988; Alloway, 1995; Holm *et al*., 2003). Soil organic matter (SOM) is also an important factor (Holm *et al*., 2003; Kabata-Pendias and Mukherjee, 2007). Sauve *et al*. (2000) found that the variability in soil–water partition coefficients (K_d) for cadmium collected from over 70 different studies was largely explained by differences in soil pH, soil organic matter content and total cadmium concentration. Strobel *et al*. (2005) observed that anthropogenic cadmium may

[1] It is estimated that around 13.6 tonnes per year of cadmium are added to soils from the application of sewage sludge to land (ECB, 2007).

be more readily released from soil than pedogenic cadmium associated with soil minerals such as apatite.

Organic matter may be better at keeping cadmium unavailable than specific and non-specific adsorption to inorganic mineral surfaces (Holm *et al*., 2003; ATSDR, 2008). Strobel *et al*. (2005) noted that the addition of dissolved organic carbon did not directly enhance the release of cadmium from a Danish agricultural soil but assisted in decreasing the soil pH, which resulted in more rapid cadmium leaching. A secondary factor controlling the mobility of cadmium is the presence of iron and manganese hydrous oxides, and organic matter–iron complexes (Alloway, 1995; Holm *et al*., 2003; Kabata-Pendias and Mukherjee, 2007).

Plant species and cultivars differ widely in their ability to uptake, accumulate and tolerate heavy metals including cadmium (Alloway, 1995; Environment Agency, 2009e). Lettuce, spinach, celery and cabbage are reported to accumulate cadmium while potatoes, french beans and peas take up only small amounts (Alloway, 1995). Several studies have concluded that soil pH is the most important factor controlling plant uptake and that this is linked to the concentration of cadmium in soil solution (Kabata-Pendias and Pendias, 2001; ATSDR, 2008; Environment Agency, 2009e). Liming soil to increase pH to 7 and above has been shown to reduce the mobility and plant availability of cadmium in different soils (Alloway, 1995; ATSDR, 2008).

Plants have no metabolic requirement for cadmium and the symptoms of its toxicity include stunted growth and chlorosis (Kabata-Pendias and Mukherjee, 2007). The phytotoxicity of cadmium is due to its interference with the normal metabolism of some micronutrients, its inhibitory effect on photosynthesis, its ability to disturb the transpiration and fixation of carbon dioxide, and its effect on the permeability of cell membranes (Kabata-Pendias and Pendias, 2001). The critical concentration for the phytotoxicity of cadmium has been reported in the range 5–20 mg kg^{-1} fresh weight (FW) in plant tissues depending on plant species (Kabata-Pendias and Pendias, 2001).

Dermal absorption of cadmium and its inorganic compounds from soil is not expected to be significant. USEPA (2004) recommended a dermal absorption fraction (ABS_d) of 0.001 for cadmium and this value has been used in the derivation of SGVs.

Several recent studies have recognised the potential importance of house dust as a route for exposure to cadmium (Feng and Barratt, 1994; Hogervorst *et al*., 2007). However, there are insufficient data in the literature to provide a generalised cadmium soil-to-dust transport factor. In the absence of a contaminant specific soil-to-dust transport factor, the default value of 0.5 g g^{-1} DW has been used (Environment Agency, 2009b).

In an investigation in northern Belgium, Hogervorst *et al*. (2007) looked at the relationship between adult exposure and house dust concentrations in an area that had been contaminated by zinc smelting. The cadmium loading rate in house dust was found to be significantly correlated to the cadmium concentration in soil and the distance from the dwelling to the zinc smelters. However, the main finding of the study was that the loading rates of cadmium in house dust were associated with the biomarkers of internal exposure and that this association was independent of an index to account for exposure via consumption of vegetables (Hogervorst *et al*., 2007). Feng and Barratt (1994) studied three houses and two offices in the UK; they found that cadmium concentration increased with decreasing particle size and was correlated to the house age although no relationship with soil concentration was investigated.

Table 2
The Soil Guideline Values for cadmium presented in this table should only be used in conjunction with the information contained in this briefing note and with an understanding of the exposure and toxicological assumptions contained in *Updated technical background to the CLEA model* (Environment Agency, 2009b) *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c) and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Cadmium* (Environment Agency, 2009d*).*

Land use	Soil Guideline Value (mg kg^{-1} DW) [1,2,3,4]
	Cadmium
Residential	10
Allotment	1.8
Commercial	230

Notes
[1] Figures are rounded to one or two significant figures.
[2] Based on a sandy loam soil as defined in Environment Agency (2009b) and 6% SOM.
[3] Based on lifetime exposure via oral, dermal and inhalation pathways.
[4] In applying the rules for non-soil background to the SGV, the background ADE is limited to being no larger than the contribution from the relevant soil ADE.

Soil Guideline Values

Soil Guideline Values (SGVs) for cadmium are presented according to land use in Table 2. The SGVs apply only to cadmium and its inorganic compounds. For residential and allotment land uses, SGVs are based on estimates representative of lifetime exposure. Although young children are generally more likely to have higher exposures to soil contaminants, the renal toxicity of cadmium – and the derivation of the TDI_{oral} and TDI_{inh} – are based on considerations of the kidney burden accumulated over 50 years or so (Environment Agency, 2009e). It is therefore reasonable to consider exposure not only in childhood but averaged over a longer time period.

The residential and allotment land use scenarios presented in *Updated technical background to the CLEA model* (Environment Agency, 2009b) include recommended values for estimating exposure for young children only (age classes 1–6). However, the report contains additional information on receptor and exposure characteristics that are appropriate for estimating lifetime exposure (age classes 1–18) for these standard land use scenarios. This additional information has been used to estimate lifetime exposure characteristics for the derivation of the SGVs in this technical note; these exposure characteristics are summarised in Tables 3 and 4. Where exposure characteristics for older children are not in Environment Agency (2009b), often because of a lack of underlying data, it has been assumed that:

- for children up to the age of 12 (age classes 7–12) the data for young children are most applicable;
- for children aged 12–16 (age classes 13–16) behaviour will be similar to adults.

Table 5 presents default inhalation rates for all age classes according to age and sex for the allotment land use based on short-term exposure. This table extends the data presented in Table 4.15 in Environment Agency (2009b) and has been calculated using the same methodology (Environment Agency, 2009b; Lordo *et al*., 2006).

It is important to note that for the most significant exposure pathway for cadmium (i.e. the consumption of homegrown produce) the receptor data have been robustly estimated from UK data for all age classes (Environment Agency, 2009b).

Analytical limits of detection[2] for total cadmium concentration in soil depend on the analytical technique used and range from 0.1 to 0.3 mg kg^{-1} DW with limits of quantification[3] ranging from 0.5 to 1.5 mg kg^{-1} DW. Limits of detection and quantification can vary due to the sample matrix and the range, sensitivity, set-up of the instrumentation being used. MCERTS[4] accredited analytical methods for testing for total cadmium in soil are available.

Table 3
Default exposure characteristics for lifetime exposure for the standard residential land use

Age class	Exposure frequencies (day year^{-1})		Dermal		Inhalation		Occupancy periods (hours day^{-1})		Soil-to-skin AF (mg cm^{-2})		Soil and dust ingestion rates (g day^{-1})
	Soil / dust ingestion	Homegrown produce	Indoor	Outdoor	Indoor	Outdoor	Garden	Indoor	Indoor	Outdoor	
1	180	180	180	180	365	365	1	23	0.06	1	0.1
2	365	365	365	365	365	365	1	23	0.06	1	0.1
3	365	365	365	365	365	365	1	23	0.06	1	0.1
4	365	365	365	365	365	365	1	23	0.06	1	0.1
5	365	365	365	365	365	365	1	19	0.06	1	0.1
6	365	365	365	365	365	365	1	19	0.06	1	0.1
7	365	365	365	365	365	365	1	19	0.06	1	0.1
8	365	365	365	365	365	365	1	19	0.06	1	0.1
9	365	365	365	365	365	365	1	19	0.06	1	0.1
10	365	365	365	365	365	365	1	19	0.06	1	0.1
11	365	365	365	365	365	365	1	19	0.06	1	0.1
12	365	365	365	365	365	365	1	19	0.06	1	0.1
13	365	365	365	365	365	365	1	15	0.06	0.3	0.05
14	365	365	365	365	365	365	1	15	0.06	0.3	0.05
15	365	365	365	365	365	365	1	15	0.06	0.3	0.05
16	365	365	365	365	365	365	1	15	0.06	0.3	0.05
17	365	365	365	365	365	365	1	16	0.06	0.3	0.05
18	365	365	365	365	365	365	1	16	0.06	0.3	0.05

[2] The amount of a substance that can be detected, but not quantitatively measured
[3] The amount present of a substance that can be quantitatively measured
[4] Environment Agency's Monitoring Certification Scheme

Table 4
Default exposure characteristics for lifetime exposure for the standard allotment land use

Age class	Exposure frequencies (day $year^{-1}$)		Dermal		Inhalation		Occupancy period (hours day^{-1})	Soil-to-skin AF (mg cm^{-2})	Soil and dust ingestion rates (g day^{-1})
	Soil / dust ingestion	Homegrown produce	Indoor	Outdoor	Indoor	Outdoor	Allotment	Outdoor	
1	25	180	0	25	0	25	3	1	0.1
2	130	365	0	130	0	130	3	1	0.1
3	130	365	0	130	0	130	3	1	0.1
4	130	365	0	130	0	130	3	1	0.1
5	65	365	0	65	0	65	3	1	0.1
6	65	365	0	65	0	65	3	1	0.1
7	65	365	0	65	0	65	3	1	0.1
8	65	365	0	65	0	65	3	1	0.1
9	65	365	0	65	0	65	3	1	0.1
10	65	365	0	65	0	65	3	1	0.1
11	65	365	0	65	0	65	3	1	0.1
12	65	365	0	65	0	65	3	1	0.1
13	25	365	0	25	0	25	3	0.3	0.05
14	25	365	0	25	0	25	3	0.3	0.05
15	25	365	0	25	0	25	3	0.3	0.05
16	25	365	0	25	0	25	3	0.3	0.05
17	258	365	0	258	0	258	3	0.3	0.05
18	258	365	0	258	0	258	3	0.3	0.05

Table 5
This table presents default inhalation rates according to age and sex for the allotment land use, based on short-term exposure. It extends information found in Table 4.15 (Environment Agency, 2009b) to all age classes.

Age class	**Inhalation rate[1] (m^3 day^{-1})**	
	Female	**Male**
1	10.3	12.5
2	18.8	19.7
3	20.7	20.4
4	19.1	20.6
5	21.3	22.9
6	24.9	25.5
7 [2]	17.6	18.5
8 [2]	20.2	20.5
9 [2]	21.8	22.7
10 [2]	25.0	26.8
11 [2]	28.4	28.7
12 [2]	19.8	21.2
13 [2]	22.7	23.3
14 [2]	24.5	26.5
15 [2]	27.2	31.2
16 [2]	28.3	32.4
17 [3]	27.4	35.7
18 [3]	25.4	34.5

Notes
[1] Assuming an hourly rate for 24 hours.
[2] Assumes the balance between light and moderate activity is half-and-half.
[3] Assumes an adult spends two-thirds of their time undertaking moderate intensity activities and one-third light activities.

Further risk evaluation

The SGVs for cadmium are based on a consideration of the total systemic exposure via the oral, dermal and inhalation routes. Dermal absorption of cadmium appears to be low compared with oral absorption and therefore, in the absence of specific toxicity data for the dermal pathway, it is reasonable to compare dermal exposure with the TDI_{oral}.

Table 6 presents the estimated contribution via each exposure pathway to total exposure at a soil concentration equal to the SGV for all land use scenarios. The ratios of oral/dermal and inhalation exposure to the relevant TDI at a soil concentration equal to the SGV are also reported. The data show that:

- consumption of homegrown produce and attached soil makes the greatest contribution to total exposure for the residential and allotment land use scenarios and is the risk driving pathway;
- soil ingestion makes the greatest contribution to total exposure for the commercial land use scenario and is one of the risk driving pathways;
- inhalation of indoor dust makes a negligible contribution to total exposure but is an important risk driver for the commercial land use because of the significantly lower potential threshold of toxicity for cadmium via the non-oral route (the TDI_{inh} is about 250 times lower than the TDI_{oral});
- background exposure is a significant contributor to total exposure for all land use scenarios.

Exposure to cadmium from non-soil sources including the diet and ambient air is high relative to the TDI_{oral} and TDI_{inh} respectively, and for young children there is the possibility that non-soil exposure exceeds 50 per cent of the relevant TDI (Environment Agency, 2009d). In deriving the SGV, a minimum proportion of 50 per cent of the TDI is reserved for exposure from soil sources and thus at representative soil concentrations greater than the SGV, the total exposure from soil and non-soil sources will exceed the TDI (Environment Agency, 2009b).

Young children tend to have the highest potential exposures to contaminants in soil; this combined with their lower body weights compared with adults means they are often at greatest risk of exposure exceeding the TDI_{oral} or TDI_{inh} (Environment Agency, 2009b). Averaging exposure over a lifetime typically results in the exposures for young children exceeding the relevant TDI, even though overall exposure over the lifetime does not (Environment Agency, 2009b). In evaluating the impact of applying lifetime exposure to the derivation of the SGV for cadmium, the total average exposure for young children (from soil and non-soil sources) over age classes 1–6 has been estimated to be about two and a half times the TDI_{oral}. This is not anticipated to be of significant toxicological concern (Environment Agency, 2009d). However, long-term exposure to levels in excess of either the TDI_{oral} or the TDI_{inh} might be associated with an increase in kidney disease in a proportion of those exposed.

The dominant exposure pathway for the residential and allotment land use scenarios is through the consumption of homegrown produce including fruit and vegetables (see Table 6). Based on the residential SGV, estimated levels of cadmium in some produce categories (notably green vegetables and herbaceous fruits) may exceed the maximum permissable levels for foodstuffs to be placed on the market under current UK regulations (EC, 2006; TSO, 2007). However, it is assumed in the SGV derivation that such produce is not sold and the amounts eaten by the householder and their family represent only a small proportion of their overall diet.

At a soil concentration equal to the allotment SGV, estimated levels of cadmium across all produce categories are below the maximum permissible levels allowed in food placed on the market (EC, 2006; TSO, 2007). However, the SGV for the allotment land use is close to the analytical limits for quantification and therefore care is necessary in the selection of the most appropriate analytical method.

Other site specific factors

The consumption of homegrown produce is the most important exposure pathway for cadmium for the residential and allotment land use scenarios. The phytoavailability of cadmium and its inorganic compounds to garden fruit and vegetables depends on a number of complex factors (Environment Agency, 2009e).

Although soil pH appears from the scientific literature to be especially important in plant uptake processes for cadmium, there is insufficient data in the literature for many individual plant species and produce groups to robustly quantify such a relationship (Environment Agency, 2009e). Most of the data collected in our supporting review applied to soils with pH in the range 6 – 8, consistent with many garden and allotment soils in the UK. The soil-to-plant concentration factors used in the derivation of the SGV are based on a geometric mean value calculated from this review and care should be taken in applying them to soils with pH values outside this range and especially at values less than five. In such cases, further site-specific investigations including the sampling of produce is recommended because the generic soil-to-plant concentration factors may not be sufficiently protective.

In circumstances where the SGV is exceeded, assessors may wish to consider cadmium phytoavailability on a site-specific basis and collect data on soil pH and soil organic matter content. Assessors undertaking a Detailed Quantitative Risk Assessment (DQRA) (Defra and Environment Agency, 2004) could also carry out further investigation (including the sampling and chemical analysis of edible parts of fruits and vegetables) to establish site-specific plant concentration factors.

Table 6
Contribution to total exposure for the relevant pathways as calculated by the CLEA software

	ADE to HCV ratios [1]		
	Residential	**Allotment**	**Commercial**
Oral ADE to HCV ratio	0.95	1.00	0.41
Inhalation ADE to HCV ratio	0.05	0.00	0.59
	Contribution to exposure from soil according to land-use (%) [2]		
Exposure pathways	**Residential**	**Allotment**	**Commercial**
Ingestion of soil and indoor dust [3]	4.6	0.3	49.7
Consumption of homegrown produce and attached soil	45.3	49.7	NA
Dermal contact (indoor)	<0.1	NA	<0.1
Dermal contact (outdoor)	<0.1	<0.1	<0.1
Inhalation of dust (indoor)	<0.1	NA	0.3
Inhalation of dust (outdoor)	<0.1	<0.1	<0.1
Inhalation of vapour (indoor)	NC	NC	NC
Inhalation of vapour (outdoor)	NC	NC	NC
Oral background	50.0	50.0	49.8
Inhalation background	<0.1	<0.1	0.1

Notes
[1] Rounded to two decimal places.
[2] Rounded to one decimal place.
[3] Treated as one pathway (see Environment Agency, 2009b).

ADE = Average Daily Exposure
HCV = Health Criteria Value
NA = not applicable (this exposure pathway is not included in the generic land use)
NC = not calculated (this exposure pathway is not included for chemical-specific reasons)

Table 7
Recommended chemical data for inorganic compounds of cadmium (at 10°C unless stated)

Chemical property	Inorganic cadmium	
Air–water partition coefficient, dimensionless	NA	
Dermal absorption fraction, dimensionless	0.001	USEPA (2004)
Diffusion coefficient in air, $m^2 s^{-1}$	NA	
Diffusion coefficient in water, $m^2 s^{-1}$	NA	
Octanol-water partition coefficient (log), dimensionless	NA	
Organic carbon-water partition coefficient (log), $cm^3 g^{-1}$	NA	
Relative molecular mass, g mol^{-1}	NA	
Soil–water partition coefficient, $cm^3 g^{-1}$	100	Environment Agency (2009e)
Vapour pressure, Pa	NA	
Water solubility, mg L^{-1}	1,620,000 (25°C)	Environment Agency (2009e)
Soil-to-dust transport factor, g g^{-1}	0.5	Environment Agency (2009b)
Soil-to-plant concentration factor, mg kg^{-1} FW per mg kg^{-1}		
Green vegetable produce	5.2×10^{-2}	Environment Agency (2009e)
Root vegetable produce	2.9×10^{-2}	Environment Agency (2009e)
Tuber vegetable produce	3.1×10^{-2}	Environment Agency (2009e)
Herbaceous fruit produce	1.6×10^{-2}	Environment Agency (2009e)
Shrub fruit produce	3.1×10^{-3}	Environment Agency (2009e)
Tree fruit produce	1.4×10^{-3}	Environment Agency (2009e)

DW = dry weight
FW = fresh weight
NA = not applicable (the CLEA model does not require these values in the derivation of assessment criteria for inorganic chemicals)

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Publication Information
This technical note presents information from Science Project SC050021.

Product code: SCHO0709BQRO-E-E

Project manager: Jo Jeffries, Science, Head Office

This work was funded by the Environment Agency's Science Department, which provides scientific knowledge, tools and techniques to enable us to protect and manage the environment as effectively as possible.

Published by: Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4UD.

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Dissemination Status:
Released to all regions
Publicly available

Legal Status and Disclaimer
The CLEA Guidance incorporates the following

1) *Science Report SC050021/SR2: Human health toxicological assessment of contaminants in soil.*

2) *Science Report SC050021/SR3: Updated technical background to the CLEA model.*

3) *Science Report SC050021/SR4: CLEA Software (Version 1.04) Handbook.*

4) *CLEA Software version 1.04 (2009)*

5) *Toxicological reports and SGV technical notes*

The CLEA Guidance can help suitably qualified assessors to estimate the risk that a child or adult may be exposed to a soil concentration on a given site over a long period of exposure that may be a cause for concern to human health. The CLEA Guidance does not cover other types of risk to humans, such as fire, suffocation or explosion, or short-term and acute exposures. Nor does it cover risks to the environment or the pollution of water.

The CLEA Guidance is non-statutory. It does not purport to interpret the policies or procedures of the Environment Agency and shall not operate as a statutory licence, waiver, consent or approval from the Environment Agency. Nothing in the CLEA Guidance shall prejudice, conflict with or affect the exercise by the Environment Agency of its statutory functions, powers, rights, duties, responsibilities, obligations or discretions arising or imposed under the Environment Act 1995 or any other legislative provision enactment, bye-law or regulation.

The CLEA Guidance describes the soil concentrations above which, in the opinion of the Environment Agency, there may be concern that warrants further investigation and risk evaluation for both threshold and non-threshold substances. These levels are a guide to help assessors estimate risk. It does not provide a definitive test for telling when risks are significant.

Regulators are under no obligation to use the CLEA Guidance.

[i] The varied colour of cadmium oxide is the result of differences in lattice defects and particle size, primarily as a result of thermal history (Greenwood and Earnshaw, 1997; ATSDR, 2008). (from front page)